



# FIELD MEASUREMENT OF AGRICULTURAL TRACTOR EXHAUST GAS EMISSIONS

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## Abstract

Two Canadian federal government departments, Agriculture and Agri-Food Canada (AAFC) and Environment Canada, are collaborating in a pilot project aimed at obtaining agricultural tractor exhaust gas emissions data under actual field conditions. AAFC's unique instrumented research tractor will provide the platform for collecting these data. This tractor was developed as a general purpose research tool, and was fitted with a series of sensors and an on-board data logger for measuring and recording tractor operational parameters such as engine speed, drawbar load, and fuel consumption as the tractor is doing normal field work. An instrumented exhaust pipe is being developed to measure exhaust gas temperature, flow, and NO<sub>x</sub> concentration with provision for future sensors for CO, CO<sub>2</sub>, and VOC. Signals from the exhaust pipe instrumentation will be logged on the tractor data logger along with the other tractor operational parameters. Field data can be used directly, or to program a laboratory dynamometer to reproduce the same engine load cycles for comparative emissions measurements on other tractor makes and models. The research will form a basis for development of emissions factors for agricultural field operations.

## Introduction

Total emissions for agriculture have been estimated from standard emissions factors and farm diesel fuel sales data. Emissions factors, often derived from steady state laboratory dynamometer tests do not account for the duty cycle of agricultural tractors.

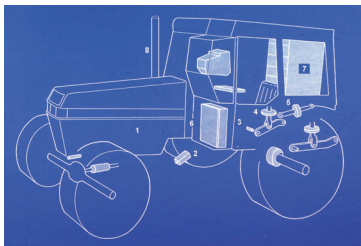
This research project is designed to measure tractor exhaust gas emissions for typical agricultural field operations. Emissions factors can be developed from these measurements, and extrapolated to a regional or national scale using data on cropping systems from agricultural census, and soil types from national soil data bases.

## Objective

1. To develop instrumentation for measurement of exhaust gas emissions of agricultural tractors under actual field conditions.
2. To document exhaust gas emissions for typical agricultural field operations to provide a basis for development of emissions factors for agriculture.

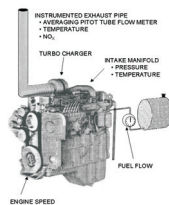


**Fig. 1** Instrumented research tractor. The cab extension accommodates the data logger operator, data logger and signal conditioning equipment.

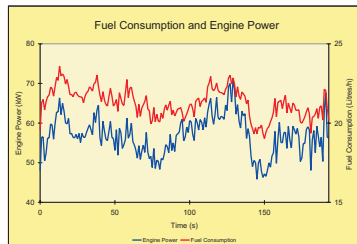


**Fig. 2** Tractor cut away showing location of various sensors.

1. engine speed
2. radar ground speed
3. implement draft
4. 3-point hitch lift
5. 3-point hitch centre
6. fuel consumption
7. data logger
8. instrumented exhaust pipe



**Fig. 3** Instrumentation for tractor exhaust gas flow and emissions measurement.



**Fig 4** Tractor fuel consumption closely tracks engine power calculated from engine speed and axle torque.



**Fig. 5** Primary tillage with a disc ripper.

## Description

The Agriculture and Agri-Food Canada instrumented research tractor (McLaughlin et al. 1993) is being used as a platform for exhaust gas emissions measurement for agricultural field operations (Fig. 1). This unique tractor was fitted with a set of instruments and an on-board data logger to measure and record tractor operational parameters while the tractor is doing normal field work (Fig. 2).

An instrumented exhaust pipe is under development (Fig. 3). Emissions sensors include a Horiba Zirconia Oxide NO<sub>x</sub> sensor, and a Horiba Mexa-700 excess oxygen sensor installed in the exhaust pipe, with provision for future installation of CO, CO<sub>2</sub>, and VOC sensors as the sensors and funds become available. Exhaust gas flow will be measured directly with an Annubar averaging Pitot tube installed in the exhaust pipe. Intake manifold pressure and temperature measurements will provide base data for determination of exhaust gas flow indirectly to provide a check on the direct measurement.

The exhaust pipe will be installed on the tractor, and the signals from the various emissions sensors logged on the tractor data logger along with the other tractor operational parameters. The combined data sets will allow development of emissions factors for engine duty cycles typical of different agricultural field operations.

## Field Experiments

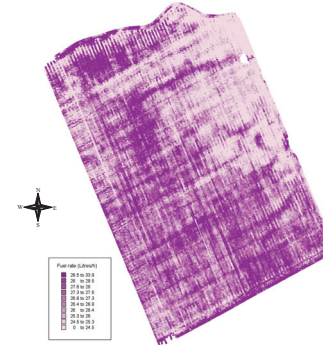
Engine power on the instrumented tractor is measured indirectly by engine speed and axle torque. Field data show that fuel consumption closely tracks engine power (Fig. 4). Using a mathematical model of the engine map, engine power can be estimated from fuel consumption and engine speed.

The tractor was fitted with a GPS (Global Position System) and the fuel consumption and position data were logged for tillage with a disc ripper in a 28 hectares (400 x 700 metres) field (Fig. 5). The fuel consumption data were subsequently mapped (Fig. 6). The map shows distinct patterns of varying fuel consumption, and engine power, which were due to both field topography (i.e. slope in direction of travel), and variability in the soil conditions.

Similar patterns of exhaust gas emissions are expected due to the variability in engine power for tillage of the field. The exhaust gas instrumentation system will allow us to quantify both the average and the variability in emissions for typical field operations for subsequent emissions factor development.

Secondary tillage in an east-west direction was done with a field cultivator in the same field (Fig. 7). Fuel consumption was subsequently mapped (Fig. 8). The north-east corner of the field was sandy, and the higher fuel consumption (darker shading) was noted. The cultivator wheels which control the operating depth, sank deeper into the sand resulting in increased tillage depth and higher fuel consumption. This is an example of an activity where the operator could have reduced fuel consumption, and likely NO<sub>x</sub> emissions, by raising the cultivator slightly while in the sandy soil.

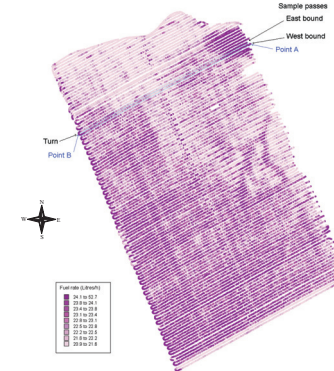
Fig. 9 shows fuel consumption for a pass with the cultivator as highlighted in Fig. 8. The pass started at point A on the east side of the field, proceeded westbound to point B on the west side, turned 180°, and returned east bound to point A on the east side. The high fuel consumption for the sandy area in the north east corner of the field is clearly evident at the beginning of the west bound pass, and at the end of the east bound pass. Turning with the implement in the soil at point B produced a very high peak in fuel consumption. This could have been prevented by simply raising the implement for turning.



**Fig. 6** Map of fuel consumption for north-south tillage of a 400 x 700 m field with a disc ripper. Patterns of varying fuel consumption are caused by both field topography and variability in soil conditions.



**Fig. 7** Secondary tillage with a field cultivator.

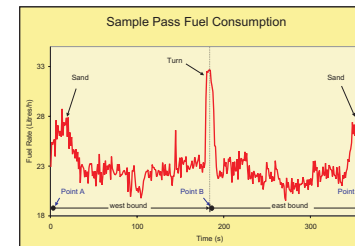


**Fig. 8** Map of fuel consumption for east-west secondary tillage in the same field as in Fig. 6.

## Future Directions

Data from the instrumented research tractor can be extrapolated to other makes and models of tractors via two methods.

1. Engine load cycle for agricultural field operations can be determined from field data collected with the instrumented research tractor. These data can be used to duplicate the engine load cycle with a programmable tractor PTO (Power Take Off) dynamometer and emissions measured for other tractors in a laboratory setting.
2. The instrumented exhaust pipe can be installed on other tractors and emissions measured directly for field operations.



**Fig. 9** Fuel consumption for west bound pass from point A to point B in Fig. 8, turn 180°, and return east bound pass from point B to point A. Note higher fuel consumption in sandy areas near point B, and for the turn.



**Fig. 10** Water brake PTO (Power Take Off) dynamometer connected to tractor PTO. With a programmable dynamometer, field data collected with the instrumented tractor can be used to duplicate engine load cycles for laboratory emissions measurement with other tractors.

## Acknowledgements

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## References

McLaughlin, N.B., L.C. Heslop, D.J. Buckley, G.R. St-Amour, B.A. Compton, A.M. Jones and P. Van Bodegom. 1993. A general purpose tractor instrumentation and data logging system. Transactions of the ASAE 36(2) 265-273.